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Automated Analysis of Shuttle Wiring Using SCAN

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Introduction

The integrity of the electrical wiring within the Space Shuttle is of critical importance. Proper operation of all computer controlled elements in the Shuttle and therefore, the safety of the crew is dependent upon it. And yet, our nation's Space Shuttle is an extremely versatile and dynamically changing vehicle. It was designed from its inception to be readily adaptable to varying payload cargo requirements from mission to mission. On a typical mission, over 1000 electrical connectors must physically undergo demating and remating in order to prepare the Shuttle for the unique functions to be carried out on a particular flight. These disconnections are due to three primary requirements. First, unique payload wire harnesses are installed for each flight for the attachment of the payloads scheduled for the mission. Second, in preparation for a mission some of the 2000 Line Replaceable Units (LRU) or "black boxes" must be removed, serviced and replaced. This action either corrects a problem that was observed during check-out at Kennedy Space Center or in flight, or is part of planned preventative maintenance procedures. Finally, wiring modifications are required within the Space Shuttle to incorporate approved critical changes of the flight systems to keep pace with the new roles required of the Shuttle. Thus there is an apparent dichotomy. On the one hand, the wiring configuration must be controlled and we would therefore like not to touch it. Yet on the other hand, some change cannot be avoided in order to accomplish the Shuttle's mission in space.

The task of insuring the flight readiness of the wiring within the Shuttle has been an expensive element of launch preparation. There are over 7000 connectors containing more than 250,000 connector pins and over 500 harnesses involved in each orbiter alone, not including those present in the External Tank and Solid Rocket Boosters. Because the Shuttle is a man-rated vehicle, the effects of each such wiring operation must be thoroughly analyzed in advance and extensively tested once completed. The current method of handling these requirements is almost purely manual and involves large amounts of manpower annually. Other complicating factors exist. For example, the retest of a connector cannot be solely the responsibility of a single functional group since individual pins through the connector are normally involved with the operation of sensors, effectors or other LRU's belonging to multiple groups such as electrical power, hydraulics, etc. While the wiring of the Orbiter is present in a computer wirelist, it is only useful for simple reports and for including wiring modifications. When analysis of the effects of demates, mates

or wiring changes is required, the only recourse available was the time consuming task of manually searching through schematics, modification package descriptions and printed versions of the wirelist. The other key limiting factor of the existing system is the timeliness of available information. The status of demated and mated connectors is at least 24 hours old while the status of wiring modifications is based upon the projected flight configuration rather than the current configuration. Prior to Lockheed winning NASA's Shuttle Processing Contract, several solutions had been attempted involving conventional computer and database technology but had proven far too expensive to implement.

Implementation

In response to this Shuttle program need, Lockheed has created the Shuttle Connector Analysis Network (SCAN). SCAN contains a front-end CODASYL database system known as the SCAN Master Database which is loaded via computer wirelist tapes. The SCAN Master Database is used to track the on going modification work taking place individually on each of the Orbiters. All changes to the actual wiring data itself occur through the SCAN Master Data Base. The remainder of the system is known as SCAN Real-time and is built directly from the SCAN Master Database.

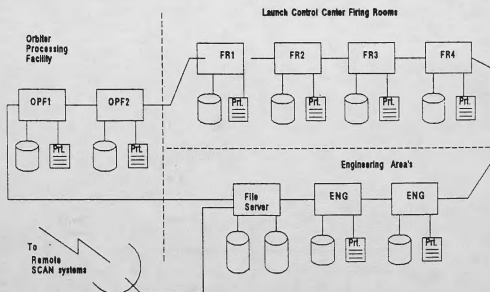


Figure 1

SCAN Real-time is a knowledge-based system utilizing a distributed network of Apollo engineering work-stations (figure 1) designed to track or assess any electrical configuration changes in the Shuttle's wiring, whether in-work or under consideration. All work-stations in the SCAN network are automatically synchronized as wiring configura-

tion changes are entered into the system. SCAN is a state-of-the-art system that is data driven and based on artificial intelligence technology. This new technology approach coupled with the emerging price and performance improvements in engineering work-stations makes the connector problem solvable at this time. The distributed network concept contributed to a solution that was paperless and provided up to the minute configuration status readily accessible to users in diverse and separate areas. Through electronic signatures responsible personnel are able to disposition and status "paper-work" from any work-station fostering parallel and independent work.

The Knowledge Base

Because of Lockheed's close association with NASA's LOX Expert System (LES) (Jami85), we had a working knowledge of how a frame-based expert system could be used to solve difficult hardware diagnostic problems. We became convinced that the capture of the Shuttle's wiring data in a knowledge base (such as used by LES) would open the door to the sophisticated extensions and spin-offs that we deemed so important. Local Lockheed management also had the insight to see that the relatively high initial investment required could pay back impressive dividends in the form of advanced diagnostics and real-time shuttle wiring schematics.

In this light SCAN was developed using a frame-based engineering knowledge base in conjunction with an inference engine and rule-like functions coded directly in Common LISP. The intent of this methodology was to mirror the thinking of system engineers as they trace orbiter wiring while remaining fast and efficient enough to rapidly analyze complex wiring structures in a very large knowledge base. Because of the size and high degree of structure anticipated in the proposed knowledge base, we were encouraged by recent experimental results (Kiyo84) which indicated that a frame based system would be the most appropriate means to represent this engineering knowledge.

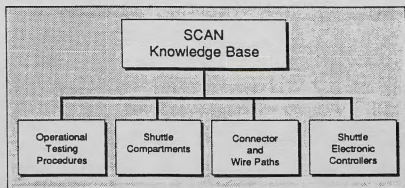


Figure 2

The knowledge base is organized as shown in figure 2. The largest

section by far is generated automatically from the local wirelist database. This accounts for about 90% of the knowledge base and consists of almost 20,000 frames representing LRU's, wire-harnesses and connectors. Additionally, wiring data is stored in approximately 90,000 internal data structures, each of which is shared by the two frames representing the connectors to which the wire is attached. This volume of data makes SCAN the one of the largest engineering knowledge base systems currently in operational use.

The remainder of the knowledge base consists of those frames which are used to represent the numerous functional and structural dependencies of the various wirelist objects. These relationships, which are implicit in the raw wirelist data, have been explicitly defined in the SCAN engineering knowledge base. For example, each frame object is categorized by type (e.g. plug, jack, transducer, assembly), part number, location and also by assembly/sub-assembly relationships. Classification by functional type has made possible the extensive use of object oriented programming techniques and "demon" dispatching via the Frame Representation Language or FRL.

Although not completely implemented, the knowledge base also contains links to the Shuttle's Operational Maintenance Instructions (OMI). OMI's are procedures that define how to perform a specific task such as the power up of the Orbiter. As an integral part of the knowledge base this data provides the definitions of operational retest requirements for all shuttle components which confirms the electrical integrity of all remated connectors.

Finally the knowledge base has been imbued with a sense of "upstream" and "downstream". That is, it includes knowledge indicating that all power sources, command initiators and indicators are at the highest level or "upstream" in functional orientation. All actuators and sensors such as valves, heaters, pumps and transducers are typically at the lowest levels or "downstream" in the functional hierarchy. Such representation, when combined with the structural or connective data from the wirelist allows SCAN to trace wires in an "intelligent" manner, and infer the state of related objects.

Capabilities

The SCAN system overview is shown in figure 3. On an individual shuttle basis, the SCAN system provides the following capabilities.

It displays the current status of connectors and LRU's through user query requests including upstream and downstream analysis. The downstream analysis locates the effects of connector demates on all LRU's located downstream of the connector in question thus providing insight into the effects caused by demating the connector. The upstream analysis locates any upstream LRU's or connectors that can impact the connector or LRU in question thus identifying its dependencies.

It also displays an impact analysis of any unresolved constraints against the initiation of an OMI or the close out of a physical area of the Orbiter.

It maintains the current demate/mate/retest status of a shuttle mission in the real-time knowledge base. This is accomplished through "logged" transaction processing by authorized personnel, tracked via electronic signature and made available to all SCAN workstations in the network.

It produces reports to the display or printer which contain extended (greater detail) information on current orbiter status or on previously logged transactions.

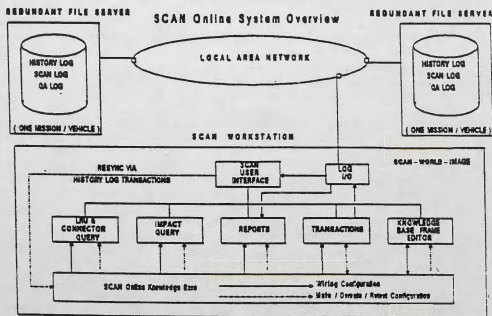


Figure 3

And finally, it can produce simplified dynamic wire trace schematics such as shown in figure 4. These schematics are drawn based on the structural and functional dependencies stored in the knowledge base. For example, upstream objects are located to the left and engineering orders that reroute wiring are automatically included. The current configuration of each component is also represented, thereby giving engineering personnel graphic visibility into the current status of the Orbiter.

The combination of artificial intelligence and the local processing power of each work-station have permitted a number of additional features to be cost-effectively added to the system. For example, during the loading of the wirelist data, each wire is traced from end to end including splices and terminal board points where many wiring traces are tied. This analysis during loading ensures consistency and also provides the source of "upstream/downstream" recognition on which much of the relational inferencing and wire trace graphics rely.

In spite of these innovations, SCAN was developed with great effort to be compatible with existing wiring configuration tracking systems. The source data is identical and many of the reports produced are similar, if not identical to existing reports. The intent was not to reproduce the old system but to provide shuttle system engineers with the degree of familiarity necessary to continue normal operations while transitioning into the new system.

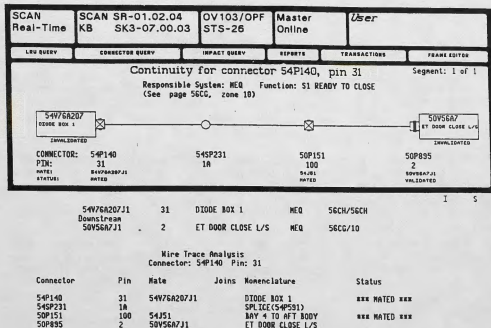


Figure 4

Benefits

In addition to the expected fruits of automating a Shuttle program critical and engineering manpower intensive task, there have already been numerous unexpected benefits in terms of delivered capability resulting from the synergy of the technology. An example is the constraint and feasibility analysis option in SCAN that is able to search all shuttle wiring for constraints against an OMI, such as Orbiter Power Up (V9001) OMI, in under 30 seconds. Other options can be used to assist troubleshooting of failed components and assess wiring configuration changes under consideration.

Because SCAN has been implemented on desktop engineering workstations in a distributed network architecture, it has brought increased visibility of current orbiter configuration to the firing rooms, offices and orbiter processing sites where such information is vital to the safe and efficient processing of each orbiter vehicle. The cur-

rent users include contractor quality assurance personnel responsible for tracking connector mate and demate status, as well as NASA and contractor system engineers responsible for the retest of all remated connectors. SCAN also rolls up the aforementioned engineering data into the management-level reports which are required for check-out and launch scheduling decisions by the test directors.

In the near future, SCAN is expected to be used in other areas such as shuttle logistics. Since SCAN logs all connector mates and demates and will soon also log LRU removals and replacements, the system will be capable of tracking the component histories required for inventory analysis.

Finally, as the internal wiring logic of LRU's is added into the knowledge base, we expect the on-line diagnostic and on-line schematic capabilities of SCAN to multiply accordingly. It is anticipated that SCAN will have real-time read access to shuttle command and control signals, which when combined with the structural and functional knowledge base will allow automated retest confirmation of many shuttle systems.

SCAN is expected to repay NASA and Lockheed for its development costs within the first two years of operation. It has gone from concept to production in little more than two years. By automating a more detailed and dynamic view of orbiter electrical configuration, SCAN has multiplied the effectiveness of engineering personnel. While currently limited to the Orbiter vehicle, its future use is expected to include the other shuttle elements (i.e. External Tank, Solid Boosters) and other areas of the Orbiter where automated wiring information is not yet available, as well as use in future programs such as the Space Station.

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